



<Research Reports> Temporal variation of stable isotopes in precipitation at Tsukuba City

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journal or publication title	Tsukuba geoenvironmental sciences
volume	2
page range	31-35
year	2006-12-26
URL	http://hdl.handle.net/2241/101612

Temporal variation of stable isotopes in precipitation at Tsukuba City

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Abstract

Monthly precipitation samples were collected at Tsukuba City from 1992 to 2006, and isotope ratios of oxygen and hydrogen were analyzed for all samples. The isotope ratios of monthly precipitation have no remarkable trend in their seasonal change. In regard to the d-excess, however, cyclic variations are observed, and the values of d-excess are relatively low in warm period (from April to September) and relatively high in cool period (from October to March). The temperature effect on isotopes in precipitation is found during cool period. A linear relationship between precipitation and δD (i.e., amount effect) are recognized in warm period. In cases of snowfall, precipitation from Baiu front and autumnal rain front, the isotope ratios in precipitation are relatively lighter than those of other cases.

Key words: precipitation, stable isotopes, d-excess, temperature effect, amount effect

1. Introduction

The stable isotopes of oxygen and hydrogen are useful to consider the soil water movement and groundwater flow system. Since the climate of Japan is relatively humid and the recharge from the precipitation is high, the stable isotope ratio of precipitation is important to estimate the water flow system.

Dansgaard (1964) considered the isotope fractionation for a stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δD) in water-vapor exchange of monthly precipitation and indicated the isotopic temperature effect and amount effect on global basis. The seasonal variation of stable isotopes in precipitation is affected by the air temperature (temperature effect) in high latitude region and the variation of stable isotopes is depends on the precipitation amount (amount effect) in low latitude. For Japan, which is located at mid latitude, the stable isotopes in precipitation are influenced by the both temperature and amount effect is expected. Jouzel *et al.* (1987) used the GCM and reported the relationship between air temperature or precipitation

amount and stable isotopes.

For Japan, Yabusaki and Tase (2005) reported the characteristics of temporal variation of $\delta^{18}O$ and δD for event precipitation in Tsukuba City from 2000 to 2002, Machida (2000) studied the spatial and temporal changes of $\delta^{18}O$ of precipitation on Miyakejima island, Yamamoto *et al.* (1993) observed the $\delta^{18}O$ and δD of meteoric water in Okayama Prefecture and indicated that the source of water vapor in Okayama using the d-excess data and Yamanaka *et al.* (2001) showed the time-space variation of stable isotopes in event-based precipitation at Kanto Plain during warm period.

To estimate the soil water movement and recharge rate using the vertical profile of $\delta^{18}O$ and δD in soil water, long-term isotopic data of precipitation is needed because the precipitation is considered to be main source of soil water. The purpose of this study is to elucidate the characteristics of temporal variation for stable isotopes in monthly precipitation at Tsukuba City.

2. Method

Monthly precipitation samples of Tsukuba City were collected. Precipitation sampler (Fig.1) with a structure which prevents the evaporation of collected precipitation (Shimada *et al.*, 1994) was settled at rooftop of the Geoscience building, the University of Tsukuba, in January of 1992 for monthly precipitation. When the samples are collected, the amount of water is also measured. Precipitation amount in this study area was calculated using the data of sampled water amount, and was compared with observed value in the Aerological Observatory, which is located in Tateno, Tsukuba, Ibaraki Prefecture, Japan (36°03'03"N, 140°07'08"E). The calculated values were collected by the observed values in the Aerological Observatory. Measurement of air temperature was also carried out routinely by the Aerological Observatory.

The isotope ratios of sampled water were measured using the CO_2 - H_2O equilibration method for oxygen and using the H_2 - H_2O equilibration method with platinum as a catalyst for hydrogen. The water sample of 1 ml was put into the glass bottle and equilibrated with the H_2 and CO_2 at 18 °C by shaking in a bath for 6 hours for hydrogen and for 9 hours for oxygen. Isotope ratios of oxygen and hydrogen were analyzed by double collector

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Fig.1 Photograph of the precipitation sampler with a structure which prevents the evaporation of collected precipitation. The diameter of the funnel is 12 cm.

stable isotope mass spectrometry system (Finnigan MAT 252, Thermo Electron Co., Ltd.), the Graduate School of Life and Environmental Sciences, University of Tsukuba. Isotope ratios are expressed as the standardized permil (‰) deviation from the V-SMOW (Vienna-Standard Mean Ocean Water),

$$\delta = \left(\frac{R_{\text{sample}}}{R_{\text{SMOW}}} - 1 \right) \times 1000 \quad (\text{‰}) \quad (1)$$

where R is the D/H or $^{18}\text{O}/^{16}\text{O}$. The analytical precision is $\pm 0.1 \text{ ‰}$ for $\delta^{18}\text{O}$ and $\pm 1.0 \text{ ‰}$ for δD . The $\delta^{18}\text{O}$ and δD values were analyzed for all samples of precipitation.

3. Results and discussion

The temporal variations of monthly precipitation amount, monthly mean air temperature, $\delta^{18}\text{O}$, δD and d-excess of monthly precipitation from January of 1992 to July of 2006 are shown in Fig.2. The d-excess value is defined by $d = \delta\text{D} - 8\delta^{18}\text{O}$.

In Tsukuba, average of annual precipitation amount is about 1240 mm from 1992 to 2005. The precipitation amount is relatively small from 1994 to 1997 and relatively large in September of 1994, September of 1996 and October of 2004. In particular the precipitation amount in October of 2004 is very large (592 mm) and corresponds to the third greatest record during a period from January of 1921 to August of 2006. From May to

July and September to October, the precipitation amount is relatively large due to baiu front and autumnal rain front. The annual mean air temperature is about $14.0 \text{ }^{\circ}\text{C}$ from 1992 to 2005. Annual air temperature is relatively low in 1993 and 1996, and relatively high from 1999 to 2000. The annual mean air temperature has a tendency to increase gradually.

Temporal variation of $\delta^{18}\text{O}$ is similar to that of δD . There is almost no annual cycle of $\delta^{18}\text{O}$ and δD values. The amount-weighted mean values of $\delta^{18}\text{O}$ and δD are -8.0‰ and -51‰ , respectively. The amount-weighted mean values of $\delta^{18}\text{O}$ and δD from April to September are -7.9‰ and -52‰ , and from October to next March are -8.1‰ and -47‰ , respectively (Table 1). During rainy season from June to July, the isotope ratios are relatively lighter than those in other periods. In particular, isotope ratios in September of 1996, January of 1998, June and July of 2000, January of 2001 and January of 2006 are very low. The autumnal rain front or baiu front is developed and intensive rainfall is fallen in September of 1996 and in June to July of 2000, which has effect on the isotope ratios of precipitation. In January of 2001, it was observed record-breaking low air temperature in Japan, and snow fell abundantly. In January of 1998 and 2006, there was also a lot of snowfall. Since the isotope ratios of snow samples show relatively lighter than those of rainfall samples (Moser and Stichler, 1980; Lambs, 2000; Hashimoto *et al.*, 2002), it is thought that the stable isotope ratios in January of 1998, 2001 and 2006 become light. The values of d-excess have the clear seasonal variation with relatively low values from April to September (warm period) and relatively high values from October to March (cool period) in every year.

δ -diagram for precipitation is shown in Fig.3. The local meteoric water line (LMWL) of monthly precipitation is $\delta\text{D} = 7.7\delta^{18}\text{O} + 11.9$ ($r^2=0.90$). This regression line almost agrees with the Global Meteoric Water Line defined by Craig (1961). The isotope ratios of precipitation from October to March (cool period) are distributed along the line of which slope is 7.6 and intercept is 25, from April to September (warm period) are distributed along the line of which slope is 7.6 and intercept is 5.

Fig.4 shows that the relationship between air temperature or rainfall amount and δD of monthly precipitation from 1992 to 2005. These samples are divided in warm period and cool period. The correlations between temperature and $\delta^{18}\text{O}$ or δD for the global scale should have been observed. Dansgaard (1964) established a linear relationship between surface air temperature and $\delta^{18}\text{O}$ for mean annual precipitation on a global basis. Clark and Fritz (1997) indicated that the heavy isotopes (^{18}O and D) of precipitation are depleted as decreasing temperature

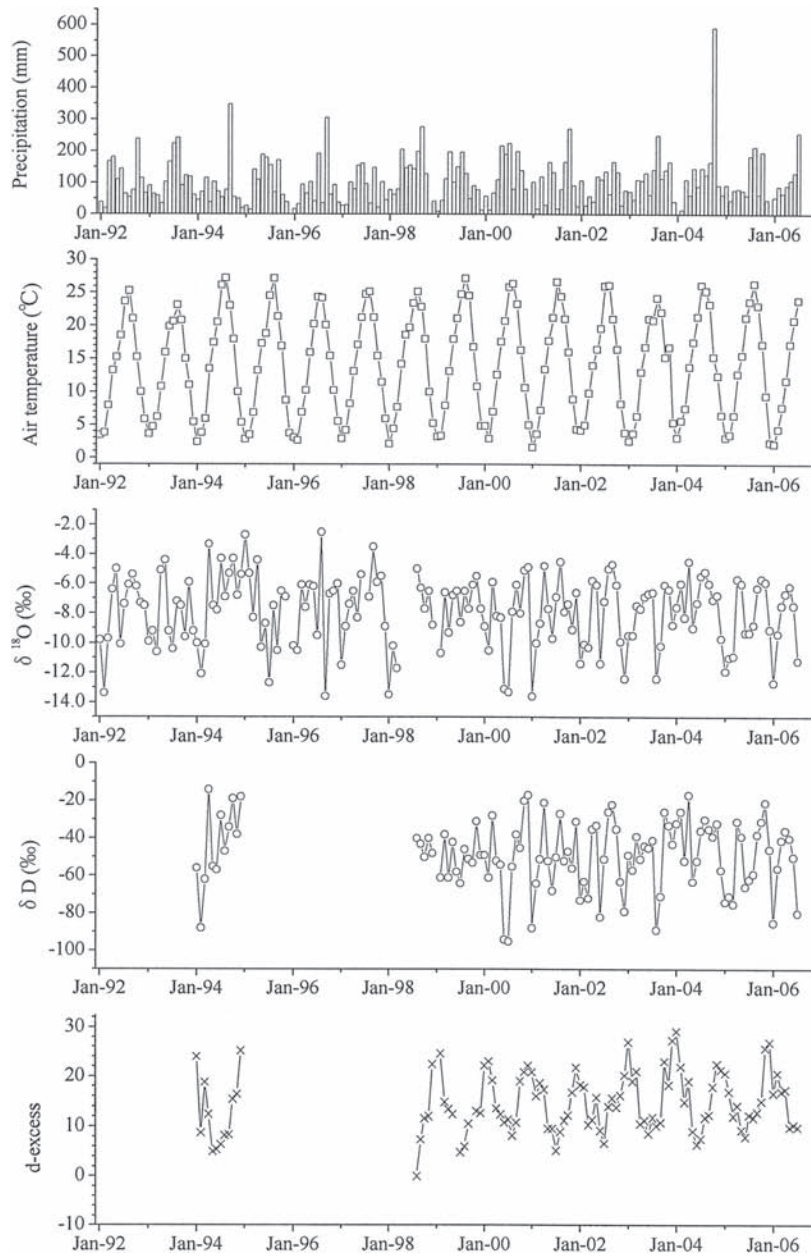


Fig.2 Temporal variation of precipitation, air temperature, $\delta^{18}\text{O}$, δD and d-excess in monthly precipitation at Tsukuba from 1992 to 2006.

Table 1 Amount-weighted mean values of $\delta^{18}\text{O}$, δD and d-excess in monthly precipitation at Tsukuba from 1992 to 2006. The month which has no isotopic data was omitted from the calculation.

	$\delta^{18}\text{O}$ (‰)	δD (‰)	d-excess
Yearly	-8.0	-51	13.1
April-September	-7.9	-52	10.1
October-March	-8.1	-47	17.9

drives the rainout processes. However, the correlation of δD with temperature for monthly data is poor because individual weather patterns, storm tracks and air mass mixing are too chaotic to develop a clear air temperature- δD relationship at the local scale. From October to March (cool period), the correlation between air temperature and δD is relatively high because rainfall amount in cool period is relatively smaller than that of other periods and it is estimated that the amount effect is relatively small in cool period (Fig.4b). Negative correlation between precipitation amount and δD is recognized from April to September (warm period), as shown in Fig.4c.

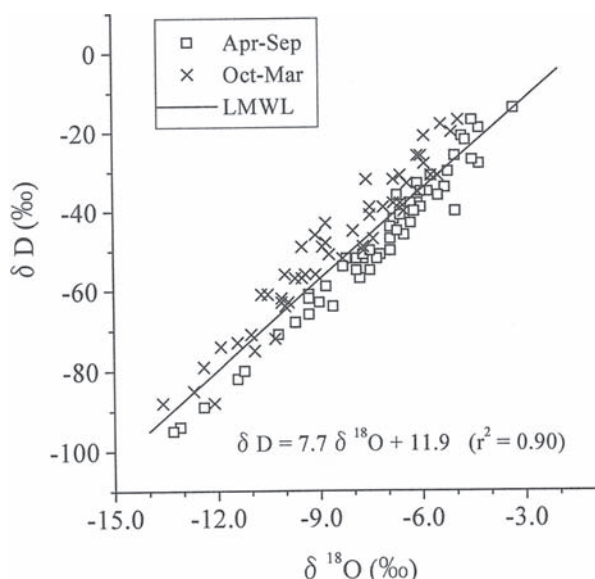


Fig.3 $\delta^{18}\text{O}$ versus δD values in monthly precipitation at Tsukuba. The data are distinguished between April to September and October to March. The numerical formula in the figure is local meteoric water line (LMWL) in Tsukuba from 1992 to 2006.

4. Conclusion

In this study, stable isotopes of oxygen and hydrogen in monthly precipitation at Tsukuba City from January of 1992 to July of 2006 were analyzed and temporal variations of $\delta^{18}\text{O}$ and δD are shown. The result of this study has proved that (1) the isotope ratios of monthly precipitation have no remarkable trend of seasonal isotopic change, (2) the $\delta^{18}\text{O}$ and δD values are relatively low when the intensive rainfall is occurred due to baiu front and autumnal rain front, and also low in snowfall, (3) The values of d-excess are relatively low in warm period (from April to September) and relatively high in cool period (from October to March), (4) there is a positive correlation between air temperature and δD in cool period (temperature effect) and negative correlation between precipitation amount and δD in warm period (amount effect).

Acknowledgements

The authors are grateful to anonymous reviewer for helpful suggestions and advice.

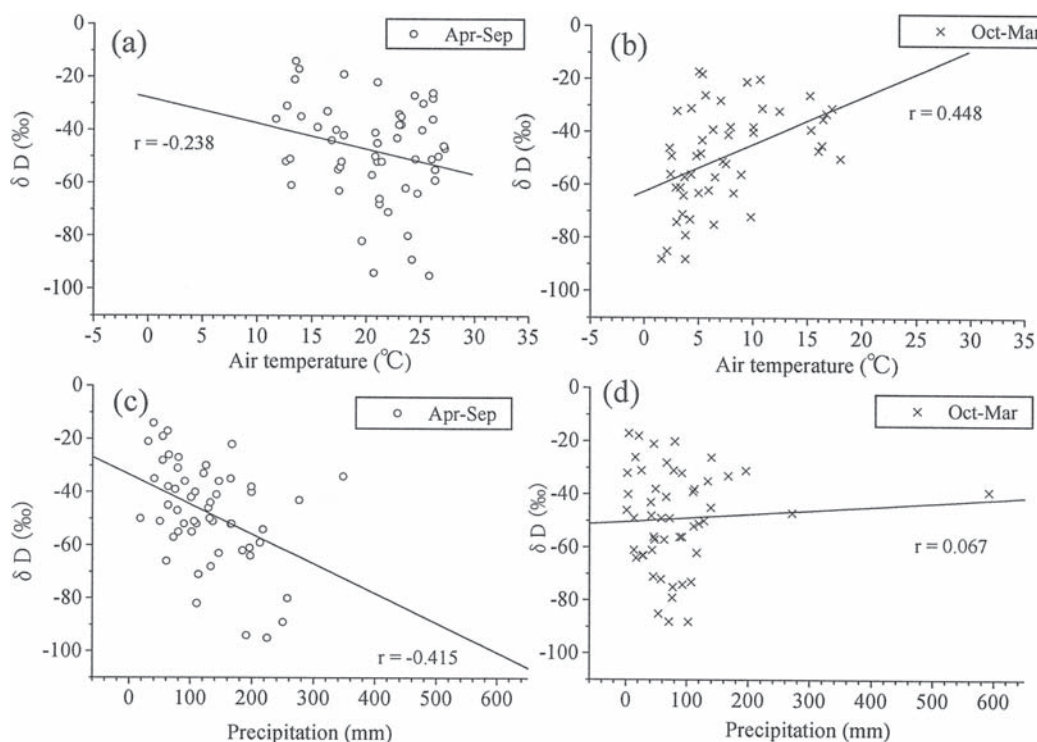


Fig. 4 δD versus air temperature and δD versus precipitation for summer period (April to September) and winter period (October to March). Regression lines are expressed by (a) $\delta\text{D} = -0.97T - 27.8$ ($r = -0.238$), (b) $\delta\text{D} = 1.79T - 62.4$ ($r = 0.448$), (c) $\delta\text{D} = -0.11P - 33.46$ ($r = -0.415$) and (d) $\delta\text{D} = 0.014P - 50.30$ ($r = 0.067$). T is air temperature and P is precipitation.

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Received 6 September 2006

Accepted 28 November 2006